New C2 Synchondrosal Fracture Classification System

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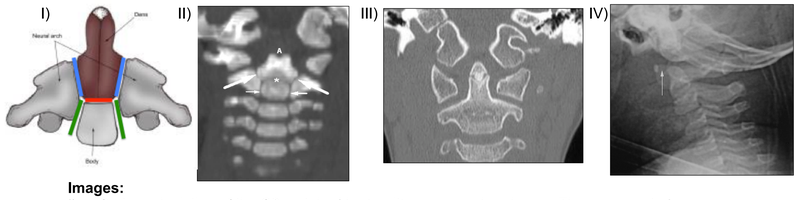
background

- C2 is the most commonly injured vertebrae in young children being uniquely susceptible to injury for a variety of reasons: C2 anatomical structure, ligamentous laxity, relatively hypotonic upper cervical musculature, upward shifted biomechanical fulcrum, and large cranial body ratio [1].
- Children can have open or incompletely fused C2 synchondroses, which serve as points of structural weakness even with minor trauma [2-4].
- A developing C2 vertebra consists of 5 ossification centers: the 2 neural arches, body, odontoid process and the chondrum terminale or os odontoideum [5]. These 5 centers are separated by 6 C2 synchondroses. Five of the C2 synchondroses are central: the right and left odontoneural synchondrosis, the right and left neurocentral synchondrosis, the odontocentral synchondrosis [6]. These synchondroses fuse by age 9 in 80% of children (range 7-9.5 years [5].
- Odontoid fractures were first classified by Anderson and D'Alonzo (Types I-III) in a 1974 roentgen series that included adults and 5 children [8]. The term "synchondrosal slip fractures" has been used to describe the most common fracture in skeletally immature patients, however, this term has been applied without distinction of which synchondrosis is involved [9, 10].
- Hosalkar et al. sought to classify the "open basilar synchondrosis" based upon the degree of anterior displacement of the odontoid fracture segment [4]. We believe this classification system has utility in diagnosis and treatment planning for C2 synchondrosal fractures, however, it only referred to fractures involving one of the central synchondroses.
- We observed a spectrum of central C2 synchondrosal fractures at our institution over the last 19 years, including 2 fracture patterns not previously reproted. We propose a new classification system which allows for distinction of C2 synchondrosal fracture types based on central synchondrosis anatomy.



Images:
I) Cartoon depiction of the C2 vertebral body with open synchondroses. The neurocentral (green), odontoneural (blue), and odontocentral (red) synchondrosis are visualized.
II) Normal synchondroses. a Coronal CT image in a 12-month-old boy show normal immature C2 anatomy. The five central C2 synchondroses— bilateral neurocentral (small arrows), bilateral odontoneural (big arrows) and the single transverse odontocentral synchondrosis (asterisk)—are all open. The apicodental synchondrosis (A) is also open and os odontoideum is not yet ossified.
III) Coronal CT of an adult C2 showing completely ossified synchondroses.
IV) A Lateral X-Ray of a 2-year-old girl.

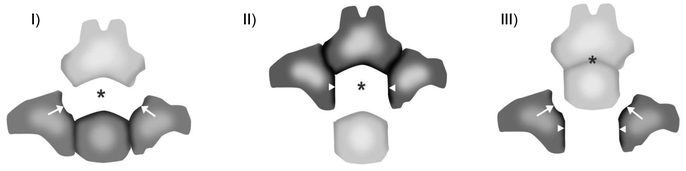
methods

- An Institutional Review Board approved our retrospective review of the imaging and hospital records of children with cervical spine fractures at a large tertiary children's hospital.
- An initial imaging database key word search for odontoid fracture, C2 fracture, C2 synchondrosal fracture, C2 synchondrosal slip fracture, C2 synchondrotic slip fracture, cervical spine CT, axis fracture, cervical spine fracture, and c-spine fracture was performed for patients < 21 years of age. All non-synchondrosal fractures were excluded. All fractures involving the apicodental synchondrosis were also excluded.
- All imaging studies of children with fractures involving the remaining 5 central C2 synchondroses were evaluated to determine fracture pattern including involved synchondroses, fracture displacement and angulation, rotation, distraction, spinal canal compromise, other adjacent fractures, and integrity of the facets and disk spaces.
- Available cervical spine MRI studies were used to assess fracture pattern, ligamentous and tectorial membrane integrity, spinal cord injury, soft tissue edema/hemorrhage, occipitoatlantal alignment, and vertebral artery patency. Hospital medical records were reviewed for additional patient data including age, gender, mechanism of injury, other related diagnoses or injuries, treatment plan and outcome.

results

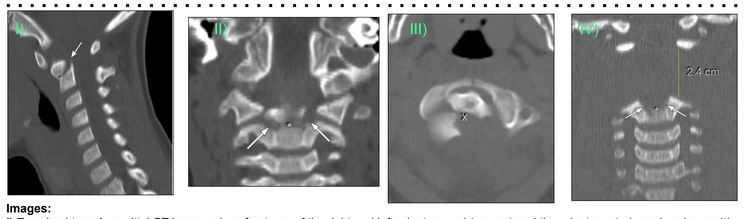
Fracture Type	Fracture Location	Intact synchondroses	*Subtype*	# pts n= 14	Treatment
I	Right & Left odontoneural + odontocentral	Right & Left neurocentral	*a*	2	Halo
			b	4	Halo/Death
			c	1	Surgical Fusion
			d	2	Death
II	Right & Left neurocentral + odontocentral	Right & Left odontoneural	*a*		
			b		
			c	1	Surgical Fusion
			d		
III	Right & Left odontoneural + Right & Left neurocentral	odontocentral	*a*		
			b	1	Halo
			c		
			d		
IV	Fracture through 1 odontoneural synchondrosis +/- a portion of its adjacent odontocentral or neurocentral synchondroses	4 of 5 including contralateral odontoneural and neurocentral, partial or complete odontocentral and partial or complete neurocentral		3	Collar/ Unknown

Table: Types of C2 synchondrosal fractures
Types I-III are complete fractures and their subtypes are defined by degree of displacement according to Holsalkar et. al, (a: 0–10%, b: 10–100%, c: >100%, and d: distraction). Type IV fractures are incomplete and nondisplaced.

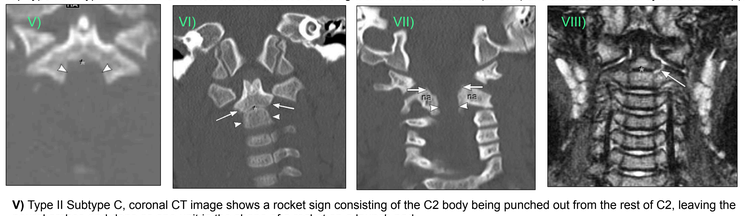


Images: Coronal diagrams of C2 synchondrosal complete fracture patterns
I) Type I fractures of the right and left odontoneural (arrows) and the odontocentral synchondroses (asterisk).
II) Type II fractures of the right and left neurocentral (arrowheads) and the odontocentral synchondroses.
III) Type III fractures through the bilateral odontoneural (arrows) and bilateral neurocentral synchondroses (arrowheads) with intact odontocentral synchondrosis (asterisk).

relevant images



Images:
I) Type I subtype A, sagittal CT images show fractures of the right and left odontoneural (arrows) and the odontocentral synchondroses (*).
II) Type I subtype B, coronal CT shows fractures of the right and left odontoneural (arrows) and the odontocentral synchondroses (*).
III) Type I subtype C, axial CT image shows fractures of the right and left odontoneural (arrows) and the odontocentral synchondroses (*).
IV) Type I Subtype D, coronal CT which shows fractures of the right and left odontoneural (arrows) and the odontocentral synchondroses (*).



V) Type II Subtype C, coronal CT image shows a rocket sign consisting of the C2 body being punched out from the rest of C2, leaving the neural arches and dens as one unit in the shape of a rocket on a launch pad.
VI, VII) Type III subtype B, coronal CT reformations show fractures through the bilateral odontoneural (arrows) and bilateral neurocentral (arrowheads) synchondroses. The neural arches (na) are in normal position.
VIII) Type IV, coronal MRI shows fracture line through only the left odontoneural synchondrosis (arrow) adjacent to the odontoid. The odontocentral synchondrosis (asterisk) is intact.

discussion

- We report a spectrum of C2 synchondrosal fractures, including 2 new fracture patterns.
- These fractures involve the 5 central synchondroses in various combinations and cannot be effectively classified using other published systems for C2 or odontoid fractures.
- The spectrum of injury for Types I, II, and III fractures ranged from less severe to deadly according to the degree of displacement by *subtype.*
- Hosalkar et al. classified fracture types into 3 subtypes based upon degree of anterior displacement of the odontoid fracture segment [4]. Our classification system uses Gore's terminology for the synchondroses [6] allowing for an anatomic description of more synchondrosal fracture patterns (Types I-IV) and it incorporates Holsalkar et al.'s classification (as *subtypes a-d),* which we found to correlate with treatment and outcomes.
- The Type II fracture extends through both neurocentral synchondroses as well as the odontocentral synchondroses. This fracture pattern has not previously been reported.
- The Type III fracture is rare accounting for only one of our 14 patients with only one previously described case [10].
- Type IV fractures, the other new C2 fracture pattern we observed, were incomplete synchondrosal fractures. In each case there was a fracture through the entirety of one of the odontoneural synchondroses. These fractures represent the mild end of the spectrum of C2 synchondrosis fractures.
- Our patients were ultimately managed in treatment groups defined by fracture type and *subtype*. Type I, II, or III *subtype a* and *b* fractures were successfully treated with halo reduction and stabilization.
- While we saw four distinct fracture patterns, we did not see any fractures that only involved a single neurocentral synchondrosis by itself or with partial extension into the adjacent odontocentral or odontoneural synchondroses.
- In addition, it is not physically possible for the odontocentral synchondrosis to be fractured by itself leaving the odontoneural or neurocentral synchondroses intact. Multiple other fracture combinations of 2 or more synchondroses are technically feasible but were never encountered.
- Our proposed classification system can easily be expanded if these are reported in the future.
- Limitations of our study include the low number of patients with these rare fractures. Likewise fractures involving the other synchondroses may have gone unrecognized and not identified in our report searches.
- Other limitations include the varied CT scanning protocols over the 19 year study period; not all patients at our institution have CT scans as part of their evaluation of suspected cervical spine trauma.

references

1. Lustrin ES, Karakas SP, Ortiz AO et al (2003) Pediatric cervical spine: normal anatomy, variants and trauma. Radiographics 23:539–560
2. Blauth M, Schmidt U, Otte D, et al (1996) Fractures of the odontoid process in small children: biomechanical analysis and report of three cases. Eur Spine J 5:63–70
3. Fassett DR, McCall T, Brockmeyer DL (2006) Odontoid synchondrosis fractures in children. Neurosurg Focus 20(2):E7
4. Hosalkar HS, Greenbaum JN, Flynn JM, et al (2009) Fractures of the odontoid in children with an open basilar synchondrosis. J Bone Joint Surg [Br] 91-B:789-96
5. Karwacki GM, Schneider JF (2012) Normal Ossification Patterns of Atlas and Axis: A CT Study. AJNR Am J Neuroradiol 33:1882–1887
6. Gore PA, Chang S, Theodore N. (2009) Cervical spine injuries in children: attention to radiographic differences and stability compared to those in the adult patient. Semin Pediatr Neurol;16:42–58.
7. Ogden JA (1984) Radiology of Postnatal Skeletal Development. Skeletal Radiol 12:169- 177
8. Anderson LD, D'Alonzo RT (1974) Fractures of the odontoid process of the axis. J Bone Joint Surg Am 56:1663–1674
9. Connolly B, Emery D, Armstrong D (1995) The odontoid synchondrotic slip: an injury unique to young children. Pediatr Radiol 25:S129–S133
10. Vining DJ, Benzel EC, Orrison W (1992) Childhood odontoid fractures evaluated with computerized tomography: case report. J Neurosurg 77:795-8.
11. Sherburn EW, Day RA, Kaufman BA, Park TS (1996) Subdental synchondrosis fracture in children: the value of 3-dimensional computerized tomography. Pediatr Neurosurg 25(5):256–259
12. WeiBkopf M, Reindl R, Schroder R, et al (2001) CT scans versus conventional tomography in acute fractures of the odontoid process. Eur Spine J 10:250-256
13. Sun PP, Poffenbarger GJ, Durham S, et al (2000) Spectrum of occipitoatlantoaxial injury in young children. J Neurosurg 93:28-39
14. Mandabach M, Ruge JR, Hahn YS, et al (1993) Pediatric axis fractures: early halo immobilization, management and outcome. Pediatr Neurosurg 19:225–232
15. Odent T, Langlais J, Glorion C, et al (1999) Fractures of the odontoid process: a report of 15 cases in children younger than 6 years. J Pediatr Orthop 19:51–54
16. Sherk HH, Nicholson JT, Chung SM (1978) Fractures of the odontoid process in young children. J Bone Joint Surg Am 60:921–924

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